Recent Advances and Analyses in Land Surface-Subsurface Processes

Norman L. Miller
Atmosphere and Ocean Sciences Group, Earth Sciences Division
University of California- Berkeley National Laboratory

First Annual California Climate Change Conference
Sacramento, California
9-10 June 2004

Acknowledgements

Research Team:

Kathy Bashford, Katharine Hayhoe[1], Jiming Jin, Reed Maxwell[2], Lehua Pan, Eric Strem[3]

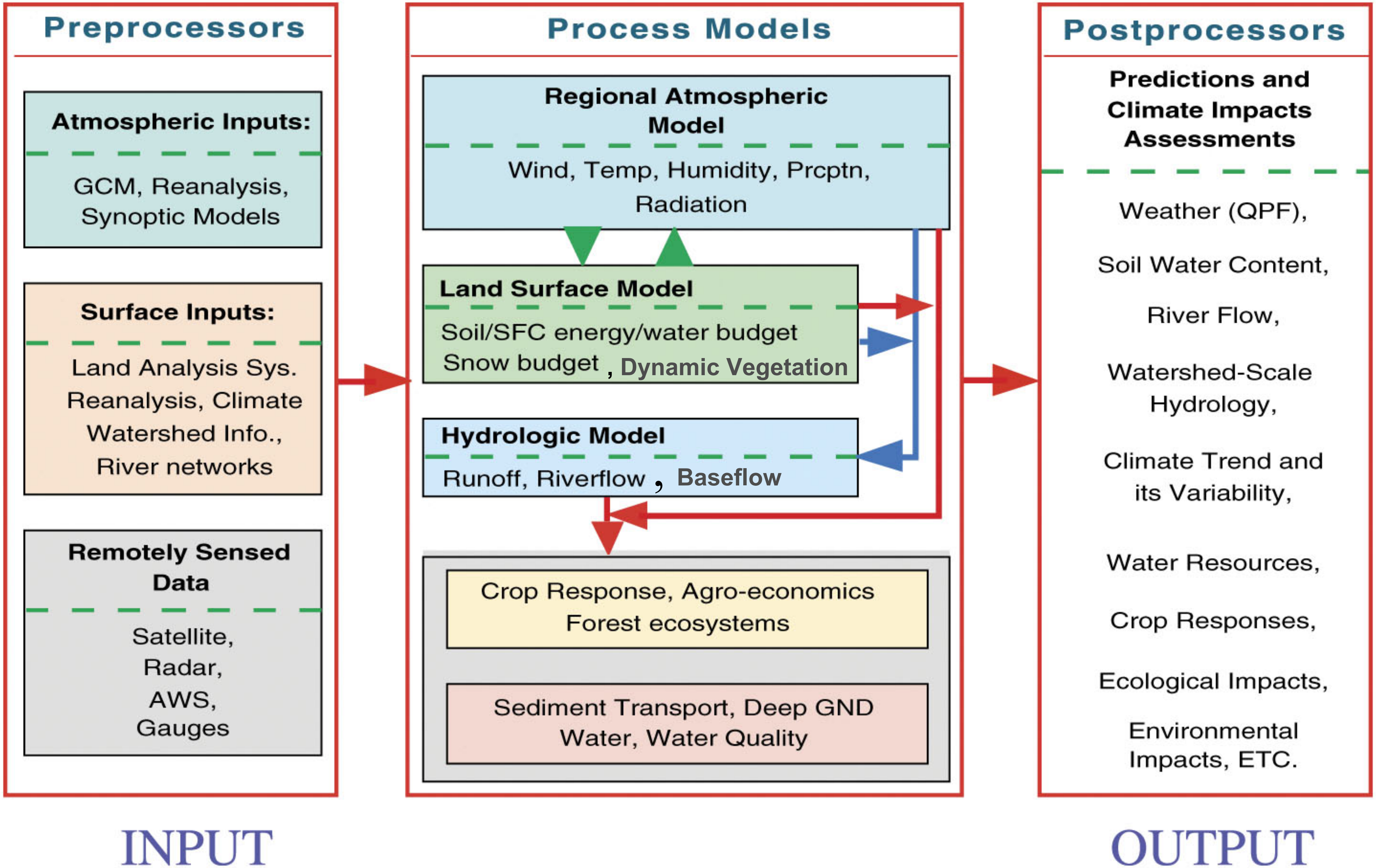
[1] University of Illinois
[2] Lawrence Livermore National Laboratory
[3] CA/NV River Forecast Center/National Weather Service/NOAA

Support for this work provided by the California Energy Commission and the U.S. Department of Energy

OUTLINE

- Defining a Regional Climate System Model Framework
- Very brief review of the CEC/EPRI Hydrologic Impacts Study
- Projected climate impacts at the surface
- New model development and comparisons
- Coupled MM5-CLM2 snow simulation analysis with observations.
- Coupled CLM2-PARFLOW water table simulation analysis with observations.
- Summary and Concluding Remarks

REGIONAL CLIMATE SYSTEM MODELING FRAMEWORK

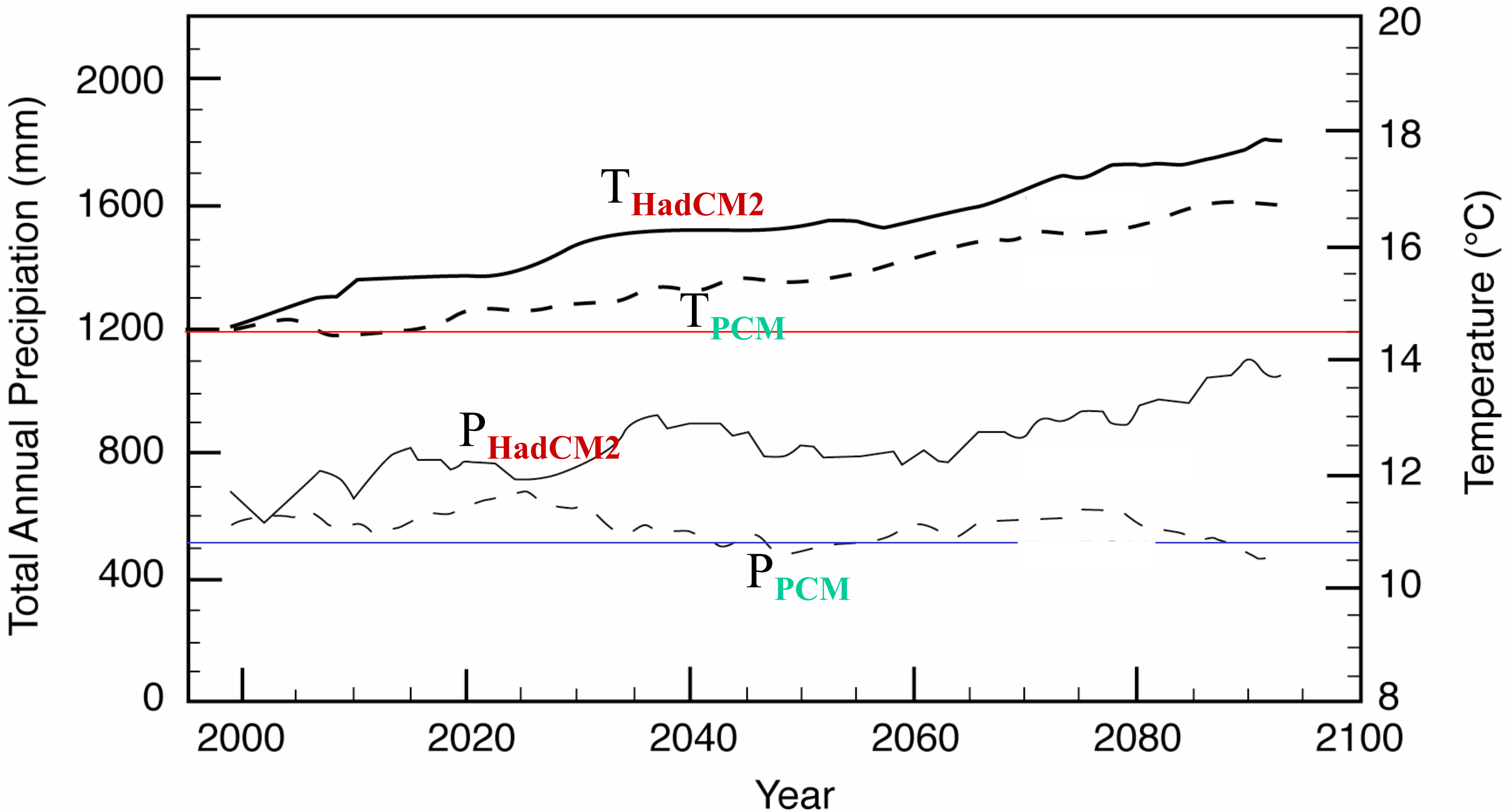


UC-Berkeley National Lab

GCM-PROJECTED CALIFORNIA MEAN AREA TEMPERATURE AND PRECIPITATION END MEMBERS

HadCM2 – High Sensitivity, relatively Warm/Wet

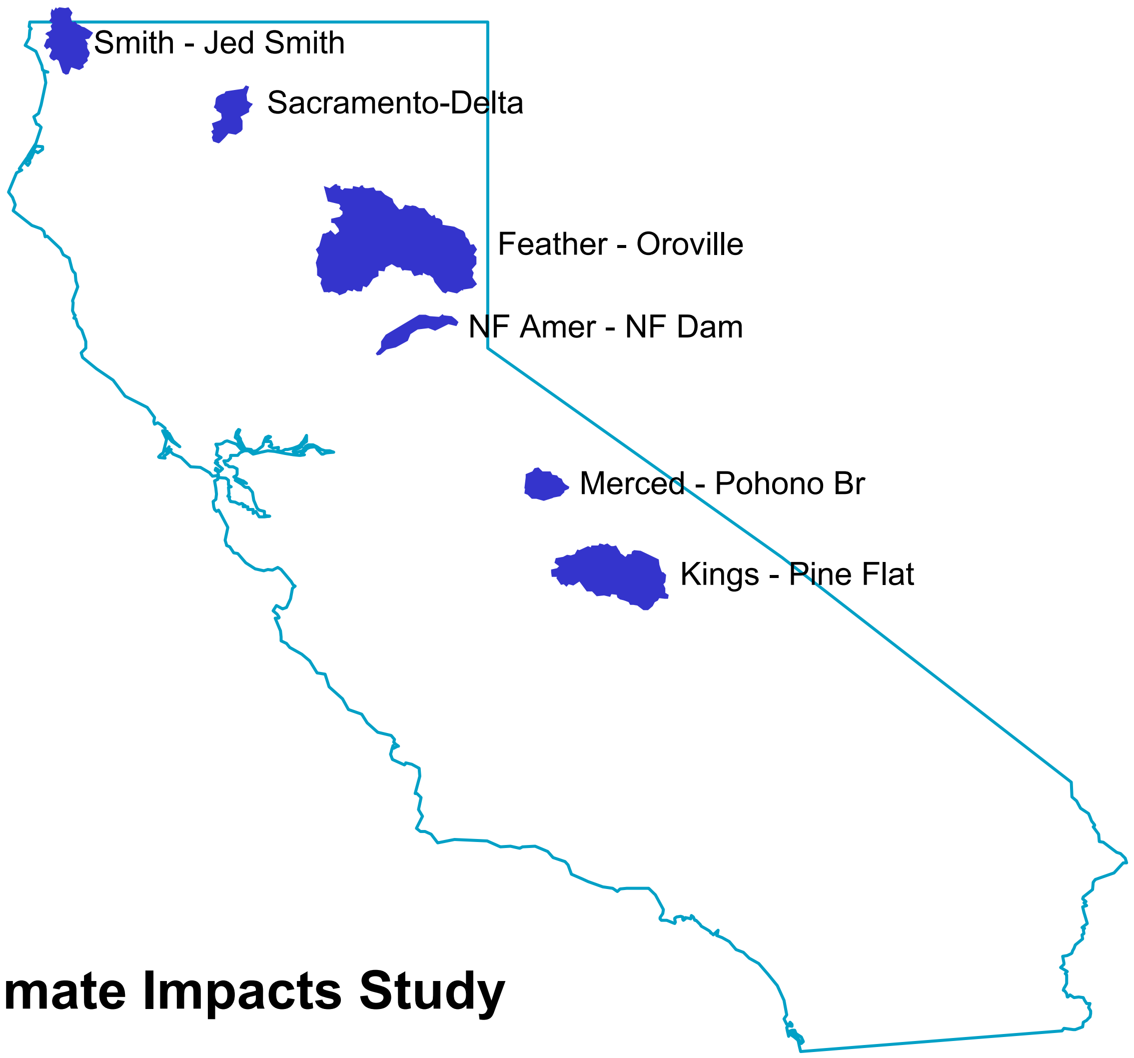
PCM – Low Sensitivity, relatively Cool/Dry



CEC-EPRI Climate Impacts Study 2001

UC-Berkeley National Lab

Six Watershed Study Basins

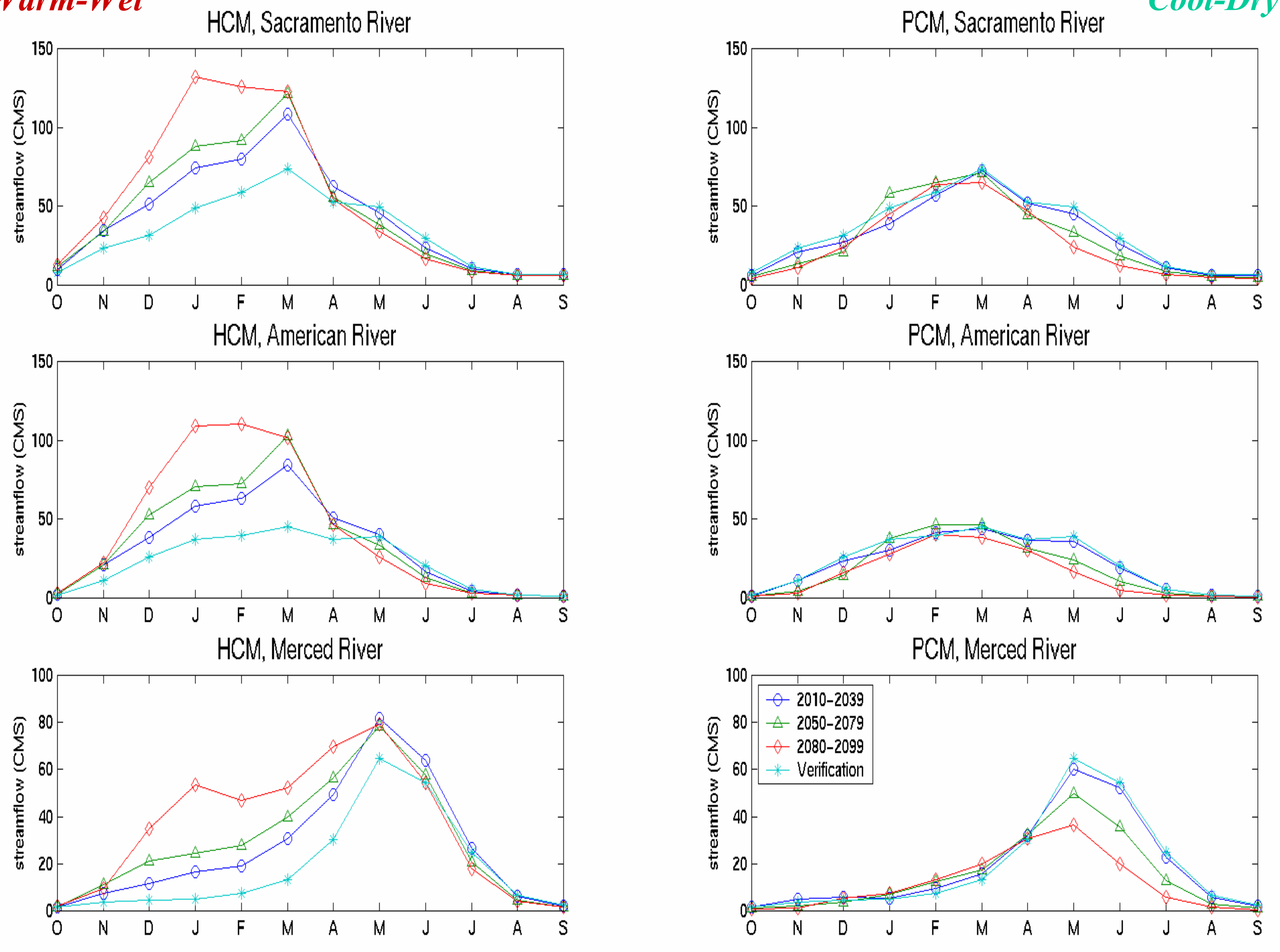


CEC-EPRI Climate Impacts Study

- **Collaboration with the CA-NV River Forecast Center/NWS/NOAA**
- **Outputs were used as CALSIM and CALVIN Monthly Forcing Data**

Streamflow: GCM-Based

Warm-Wet ***Cool-Dry***

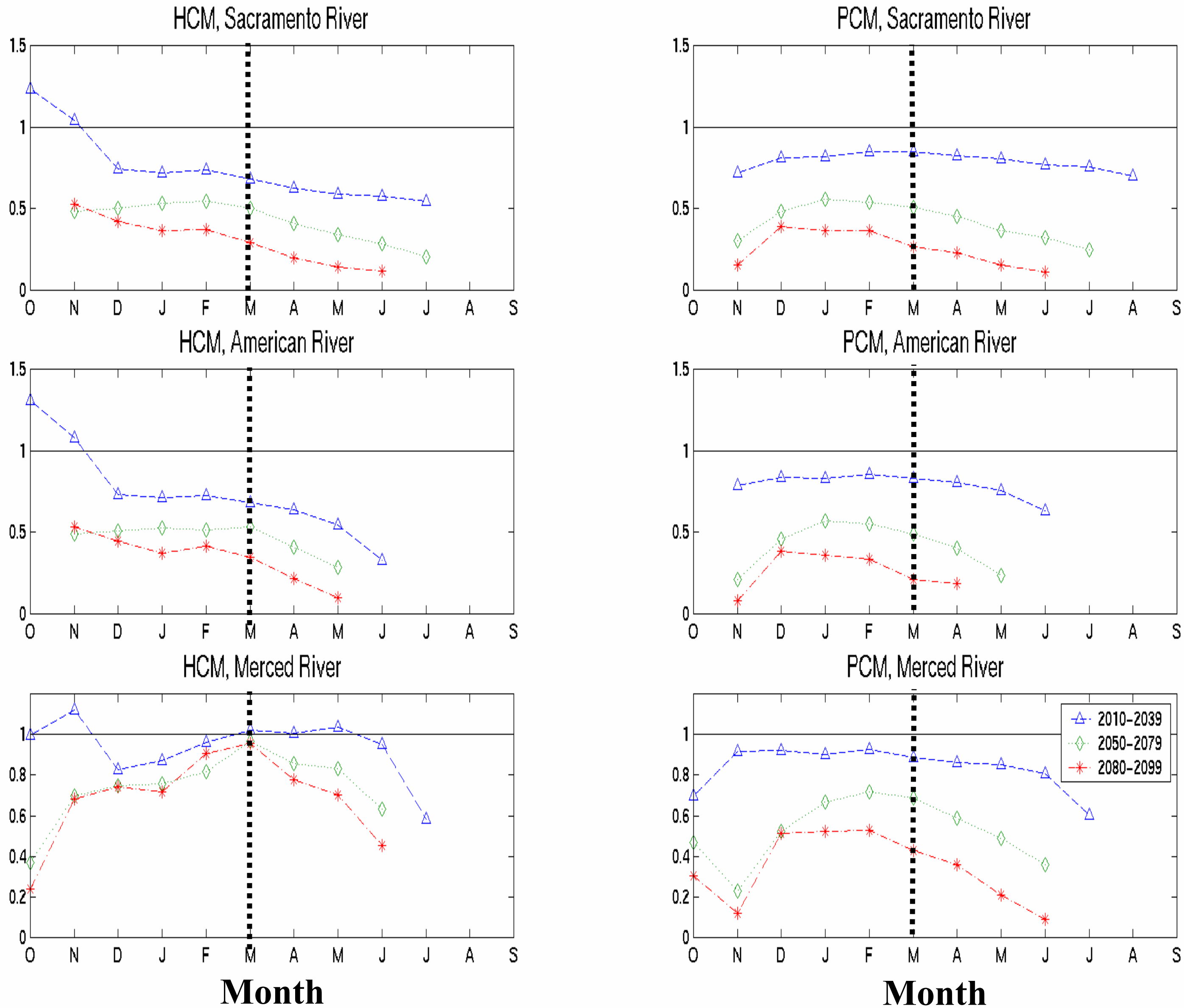


Month **Month**

Ratio of Mean-Monthly Projected Snow Water Equivalent to Baseline Snow Water Equivalent

SIGNIFICANT FINDING IS ~50% SNOW WATER EQUIVALENT ~2100 FOR ALL CASES

Warm-Wet *Cool-Dry*



CEC-EPRI Climate Impacts Study

UC-Berkeley National Lab

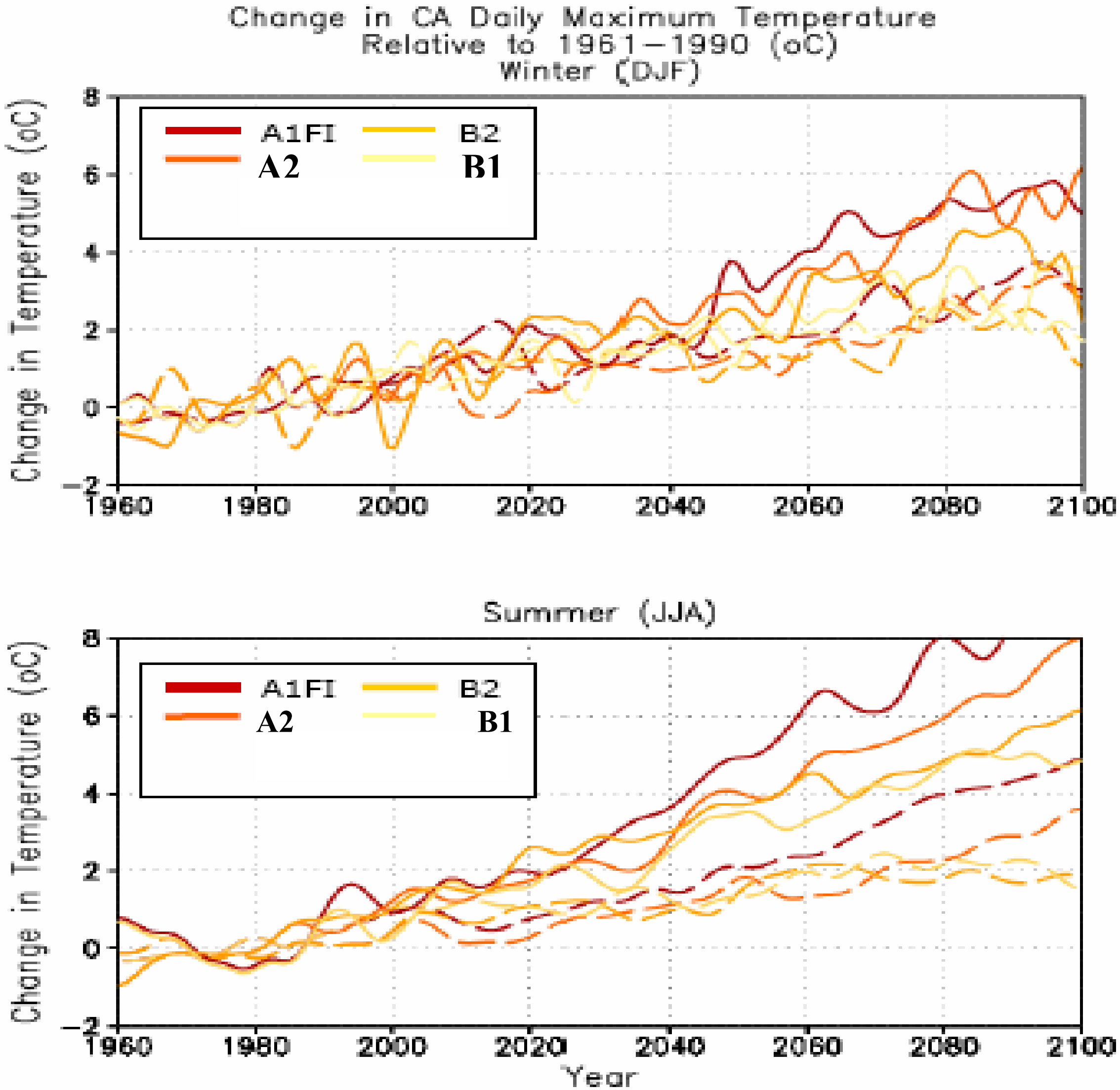
Analysis of Heat Based on Global Climate System Model Projections Using High and Med-Range Emission Scenarios

- **Emission scenarios:**
  - High emission scenario: A1fi
    ~970 ppm CO_2 by 2100, 6 x 1990 levels
  - Medium Range Emission Scenario: B1
    ~550 ppm CO_2 by 2100, 2 x 1990 levels

- **Global Climate System Models**
  - Parallel Climate Model (PCM) Low Sensitivity
  - Hadley Centre Climate Model (HadCM3) Medium Sensitivity

- **Analysis of heat**
  - Exceedence Probability for 50% and 5% occurrence
  - Number of three consecutive hot days

2004 Study

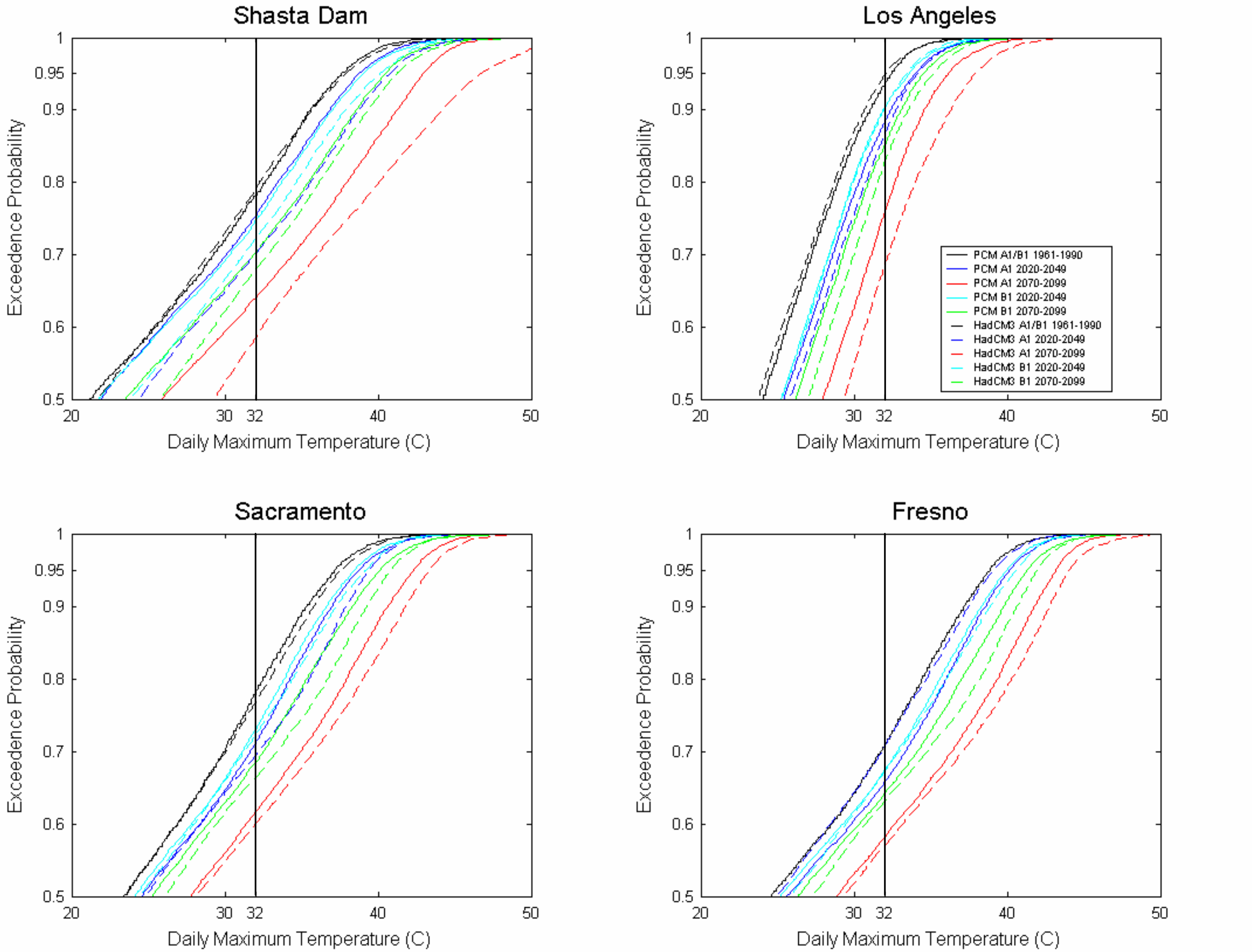


- A1fi ~970 ppm
- B1 ~550 ppm
- A2, B2 mid-range

HadCM3 (solid) and PCM (dashed) projected scenarios diverge after ~2050.

The Summer temperatures increase at a greater rate than the Winter temperatures.

UC-Berkeley National Lab



Heat Threshold (32°C) occurrence shifts by 5-30 percent. HadCM3 (dashed) and PCM (solid) for A1fi 1961-1990 (black), 2020-2049 (blue), 2070-2099 (red), and B1 2020-2049 (light green), 2070-2099 (dark green).

Increase in the number of Heat Waves at ~2100

			PCM		HadCM3		PCM		HadCM3	
			B1	A1fi	B1	A1fi	B1	A1fi	B1	A1fi
		1961-1990								
Heatwave days										
Los Angeles	days	12	28	35	24	36	44	76	47	95
Sacramento	days	58	91	101	93	104	109	134	115	138
Fresno	days	92	113	120	111	116	126	147	126	149
El Centro	days	162	185	185	176	180	191	213	197	218

… GREATER THAN 50% SNOW LOSS ~2100

A1fi – Fossil Energy Intensive Future

Model development …

- MM5 land surface schemes characterize water and energy exchanges between the atmosphere and land surface, but lack sufficiently explicit and physical descriptions for snow processes and vegetation dynamics.

- To date, no land surface schemes couple deep groundwater processes, providing feedbacks and sensitivities to both the atmosphere and deep aquifers.
  - Deep drainage has historically been assumed as a constant rate
    - BATS: 4×10^{-4} mm/s (Dickinson et al. 1986)
    - SiB: function of gravity based on slope (Sellers et al. 1989)
    - VIC: function of water table depth (Liang and Xie 2003)

- Developing a *Top-of-the-Atmosphere to Deep Groundwater* System Model provides us with the modeling tool for investigating a range of coupled feedbacks and sensitivities in a new way.

- These model developments will migrate to the Weather Research and Forecasting (WRF) model – a next generation MM5.

Description of the Community Land Model version 2

Structure:

- 5-layer snow
- 10-layer soil
- 1-layer vegetation.

Hydrology:

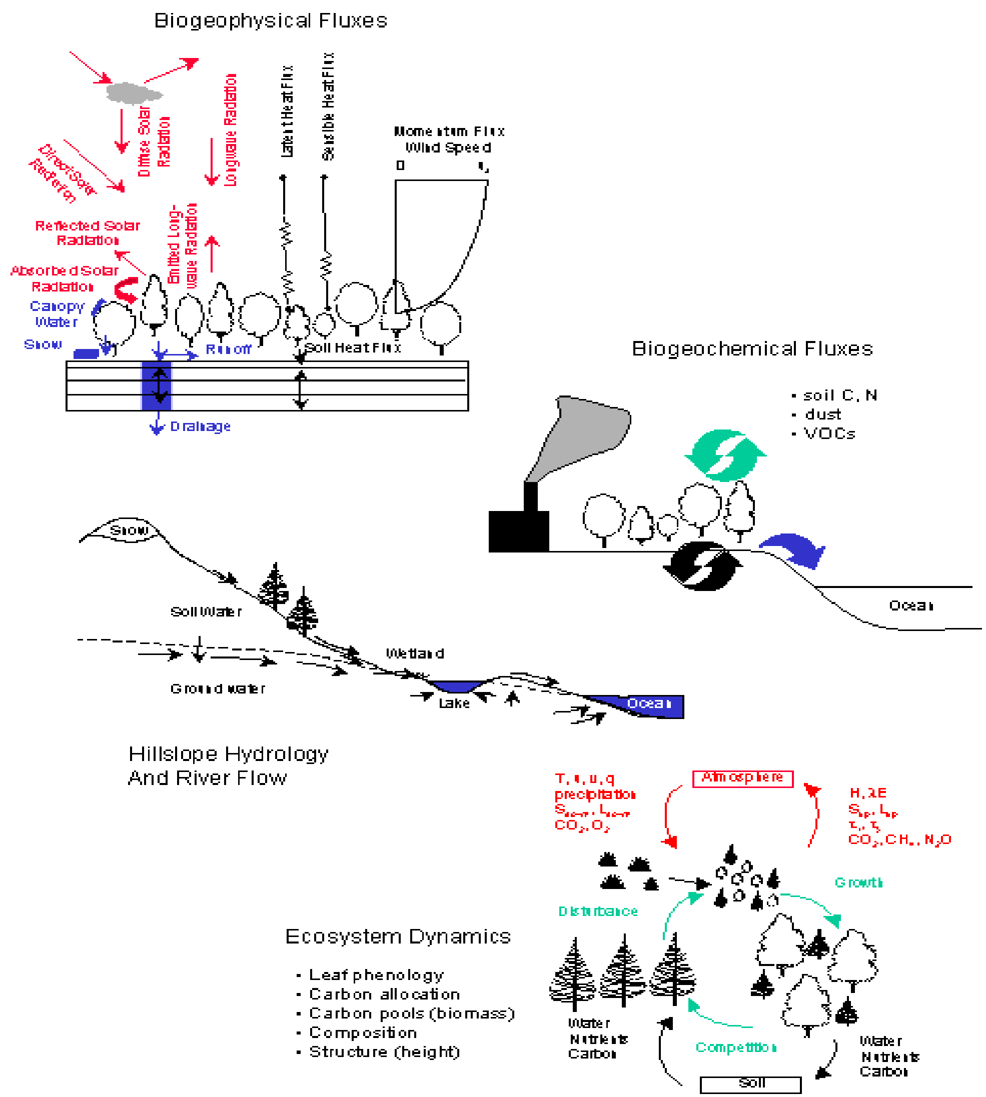
- Hillslope/Topmodel concepts
- Dynamic River Routing
- Wetlands and lake hydrology.
- Frozen soil processes

Biogeochemistry:

- Carbon Cycle Processes
- Organic matter, dust, etc.

Dynamic vegetation:

- Plant Function Types
- Succession and fire



Courtesy G. Bonan

Observations and Model Output

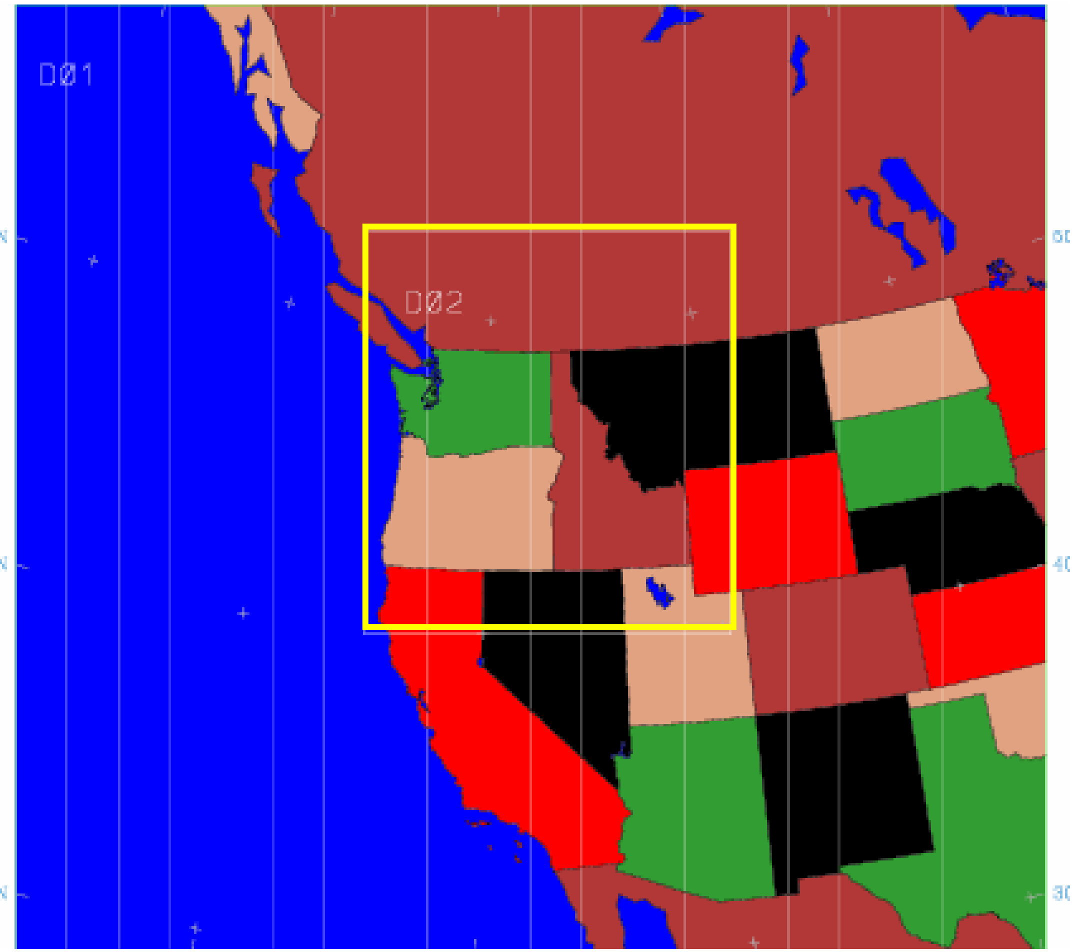
Observations:

- Standard meteorological station data
- 5 km x 5 km MODIS/Terra snow cover data
- 4 km x 4 km SeaWiFS surface albedo data.

Model Output:

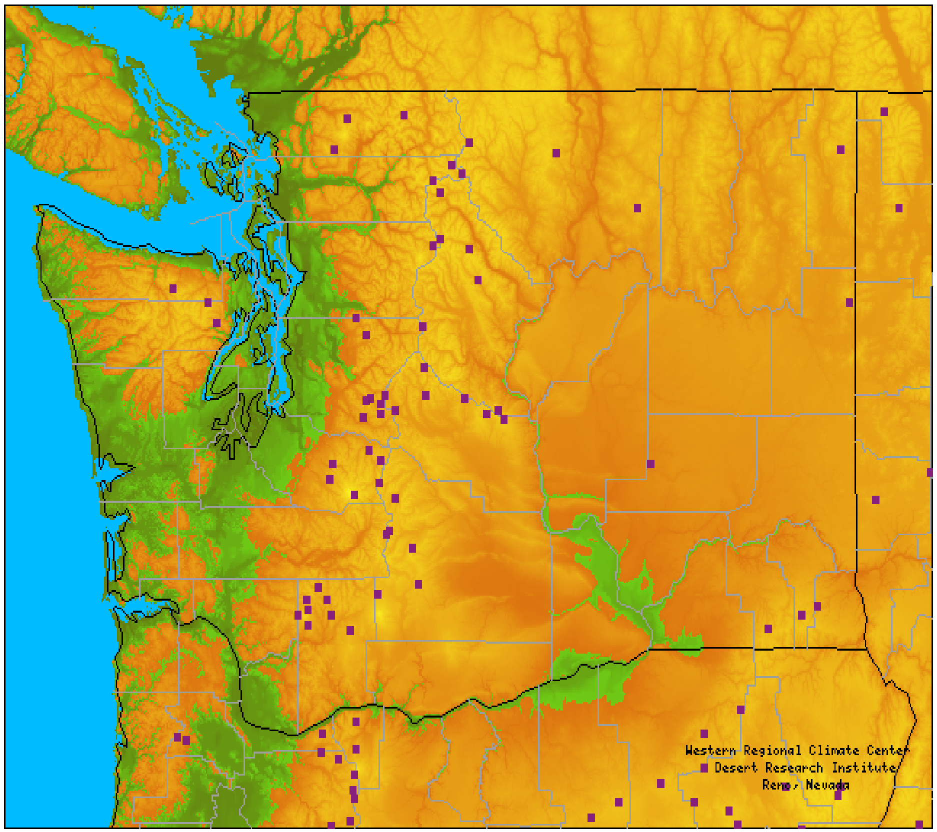
- 20km x 20km, 1 March to 31 May 2002, 1-hr data
- MM5/NOAH (Old) and MM5-CLM2 (New).

MM5-CLM2 and MM5-NOAH: Simulation and Analysis



- The domains for the Penn State-NCAR fifth-generation Mesoscale Model (MM5).
  60km and 20km
- The snowpack was initialized with LDAS and SNOTEL data.
- MM5 is driven by the 6-hr NCEP/NCAR reanalysis data during March to May, 2002.

Geographic distribution of the SnoTel Stations in Washington

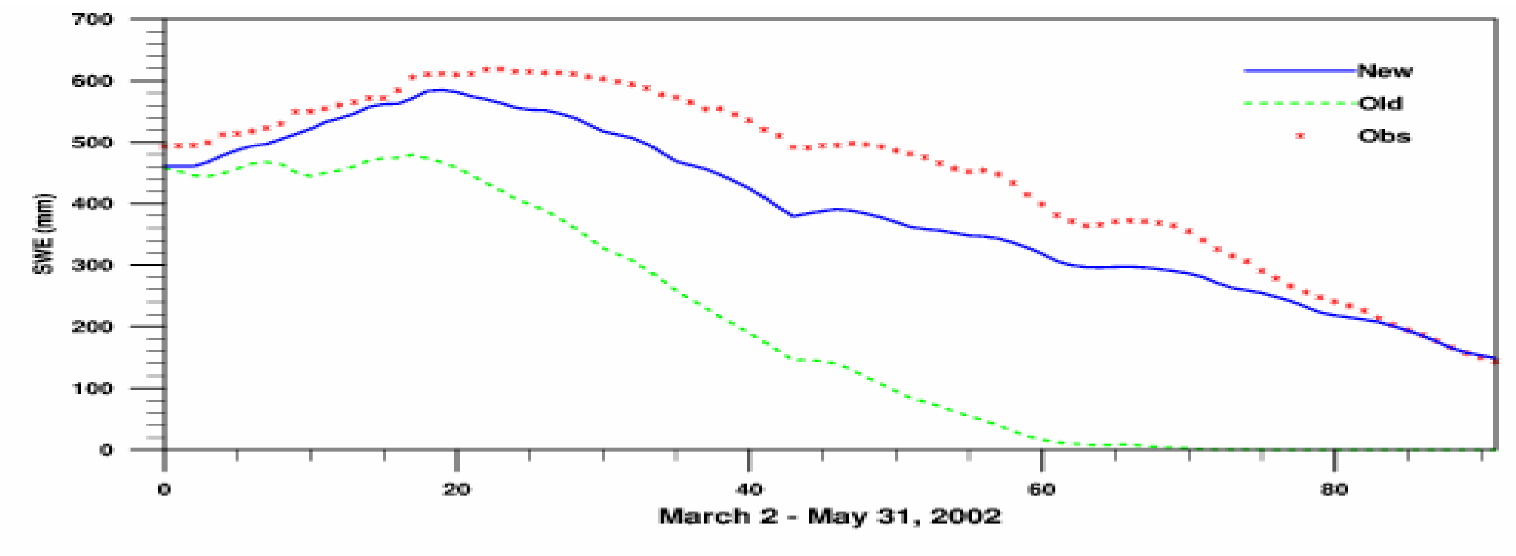


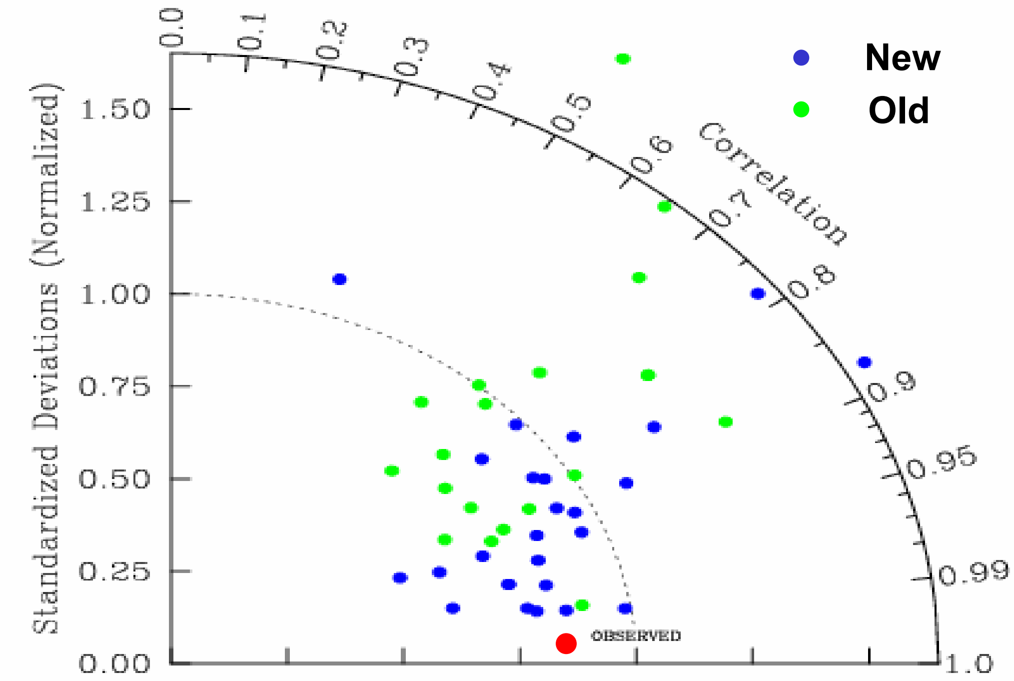
Data provided by the Western Regional Climate Center (www.wrcc.dri.edu)

- The automated Snowpack Telemetry (SnoTel) stations in Washington state.

- The datasets include:
    - daily snow depth
    - surface air temperature
    - precipitation

Snowpack Simulation over the Snotel Stations

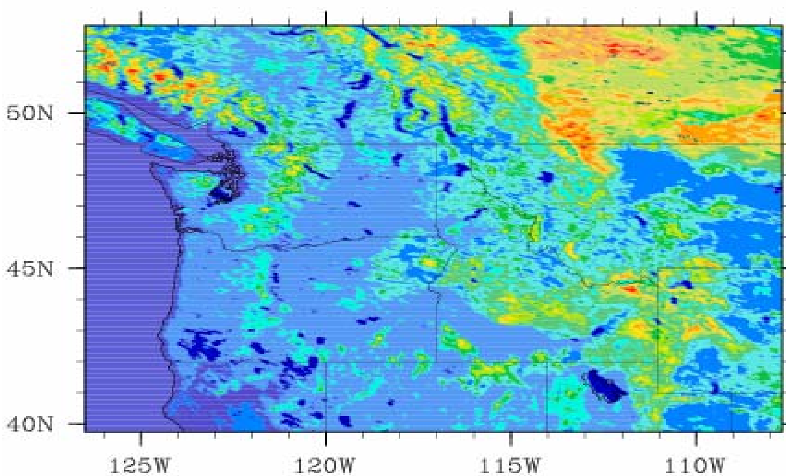




UC-Berkeley National Lab

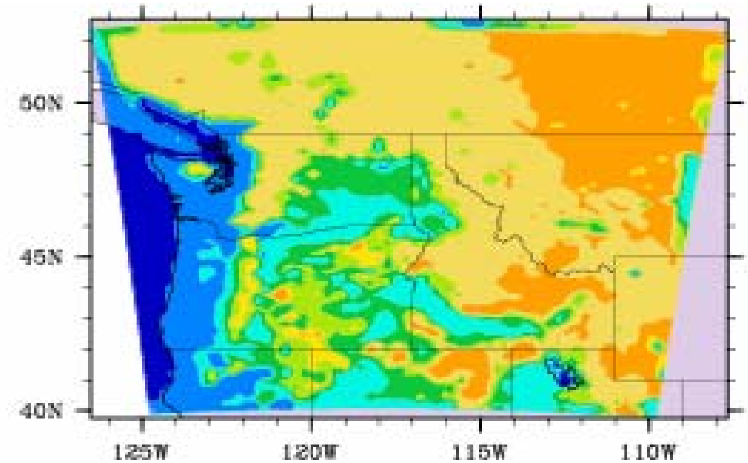
Surface Albedo

Observation (SeaWiFS)
(4kmx4km)

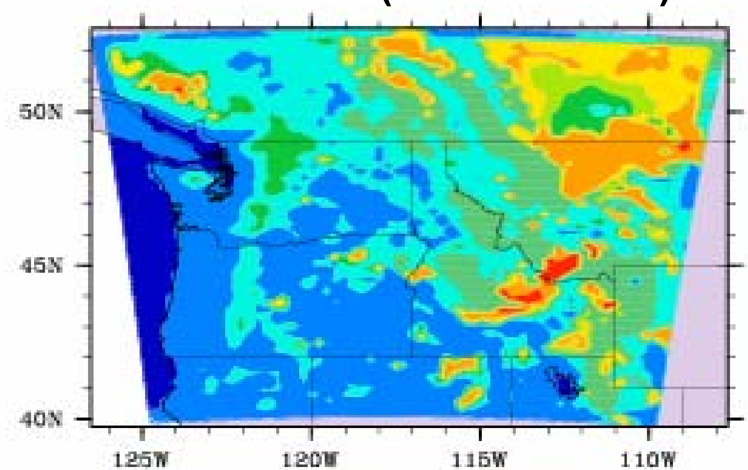


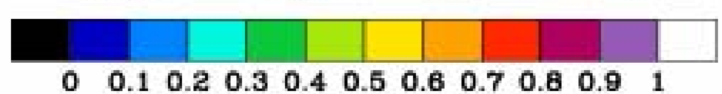
Surface albedo averaged
over March 1- 31, 2002

MM5-OLD (20km x 20km)



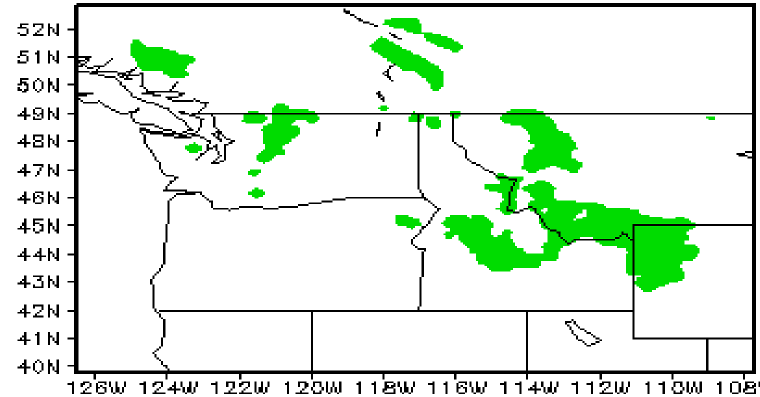
MM5-NEW (20km x 20km)



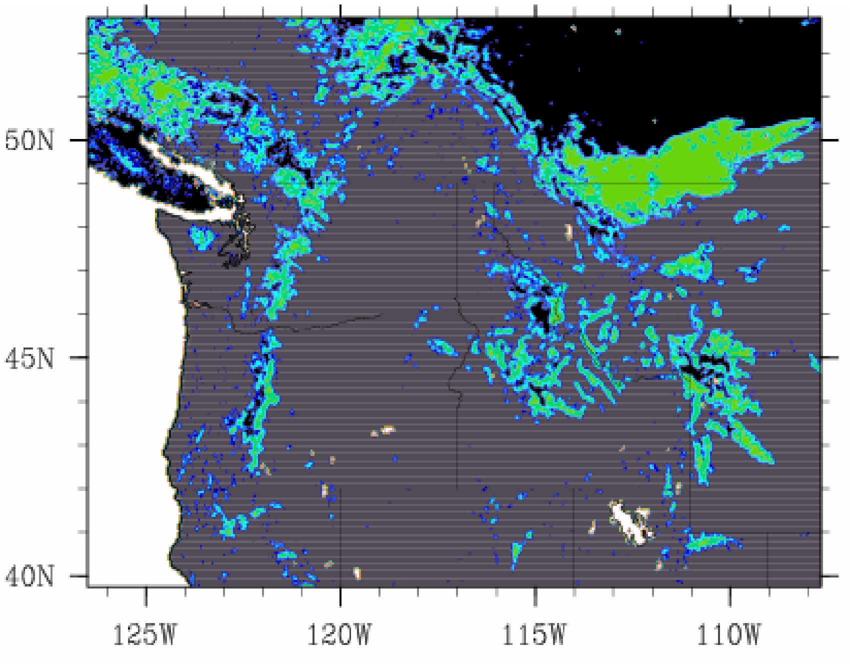


Snow cover during the snow melt period

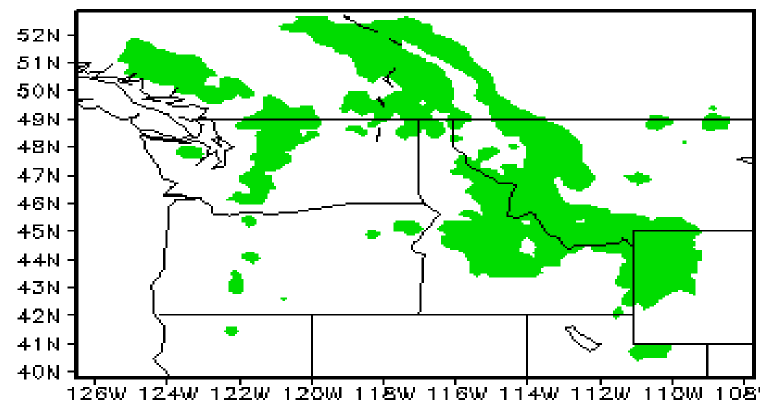
MM5-OLD (20km x 20km)



OBS (MODIS 5 km x 5km)

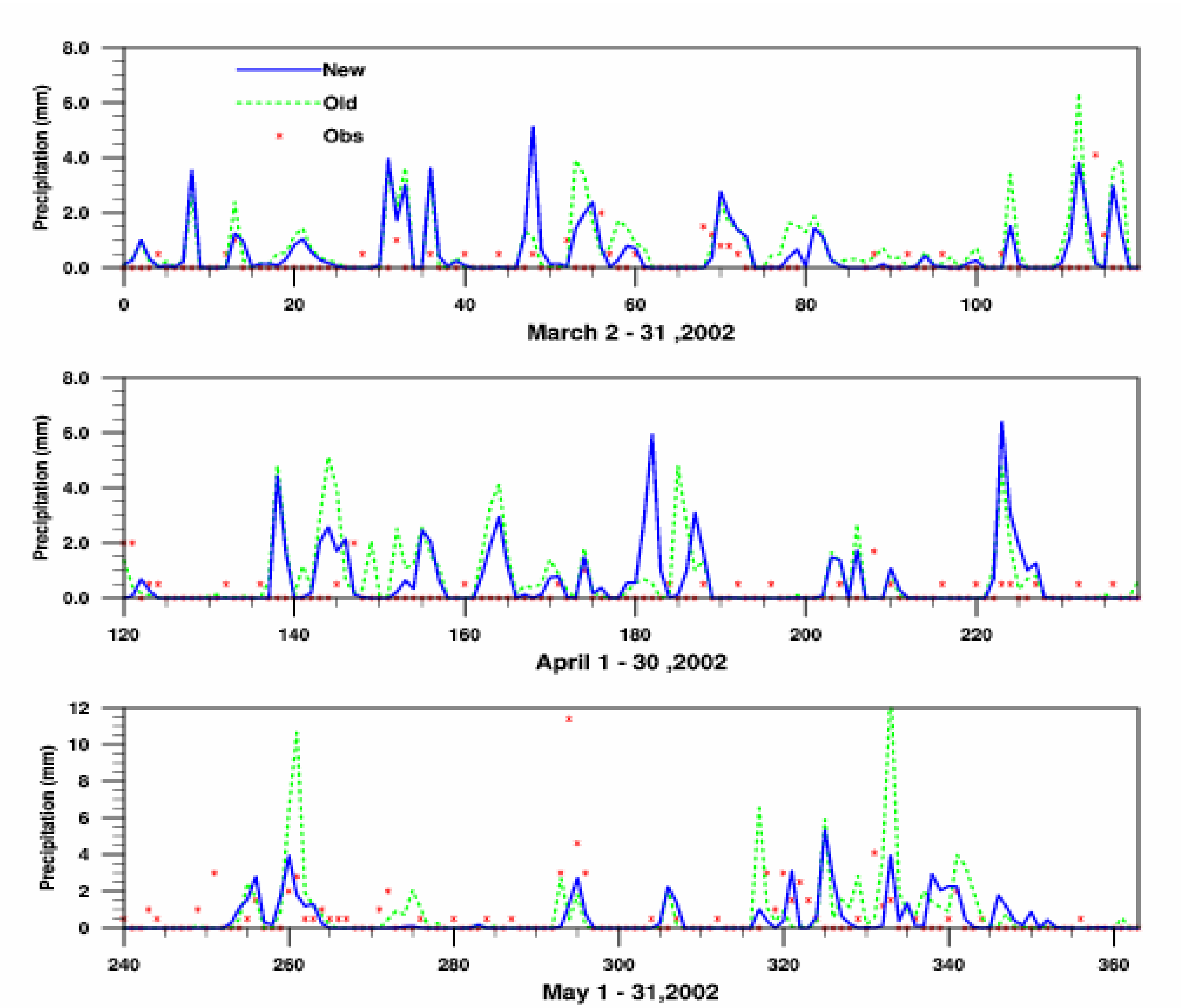


MM5-NEW (20km x 20km)



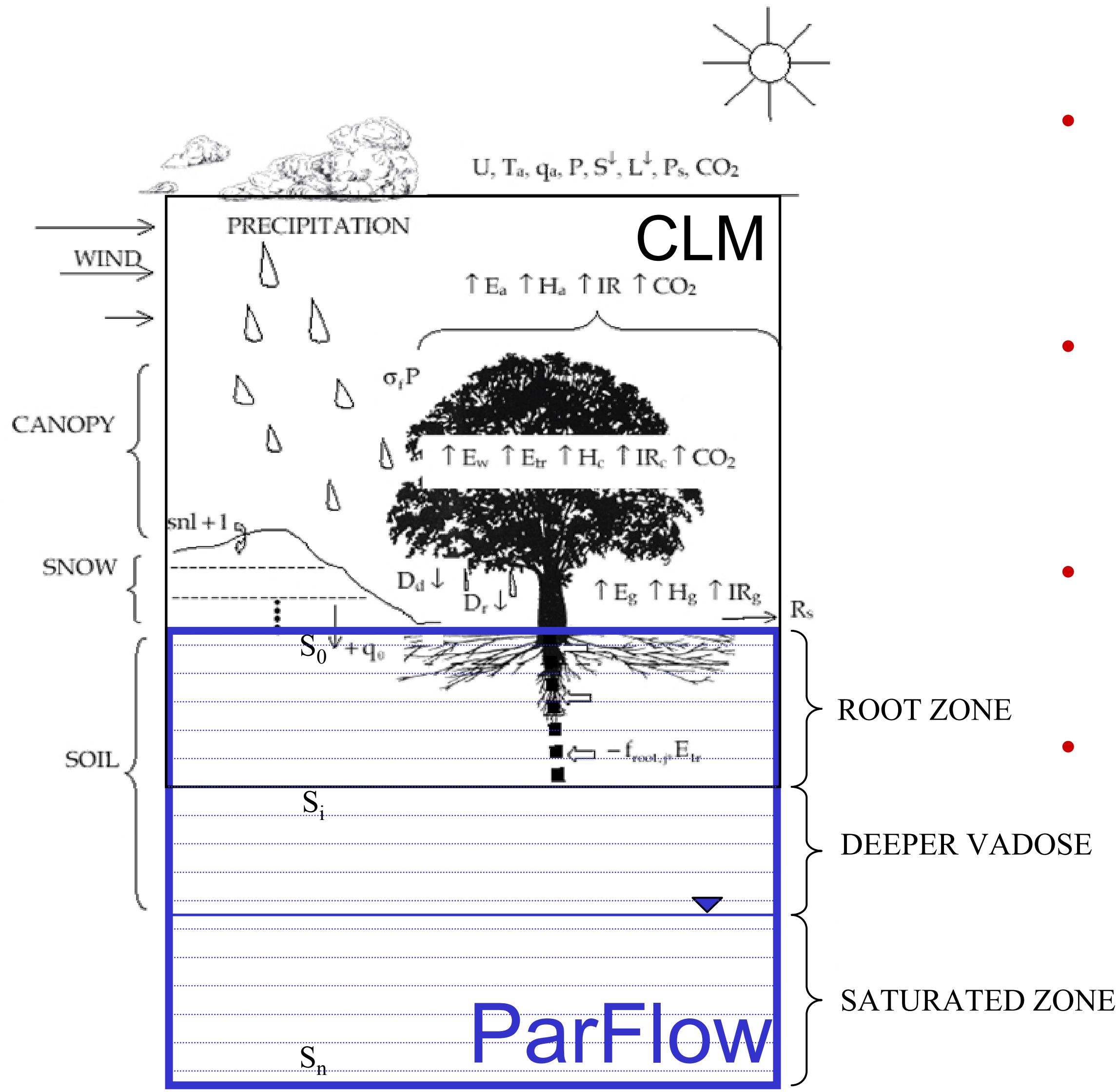
Snow cover averaged over May 1 - 31, 2002

6-hourly precipitation simulation at (-129.49°W, 51.14°N)



UC-Berkeley National Lab

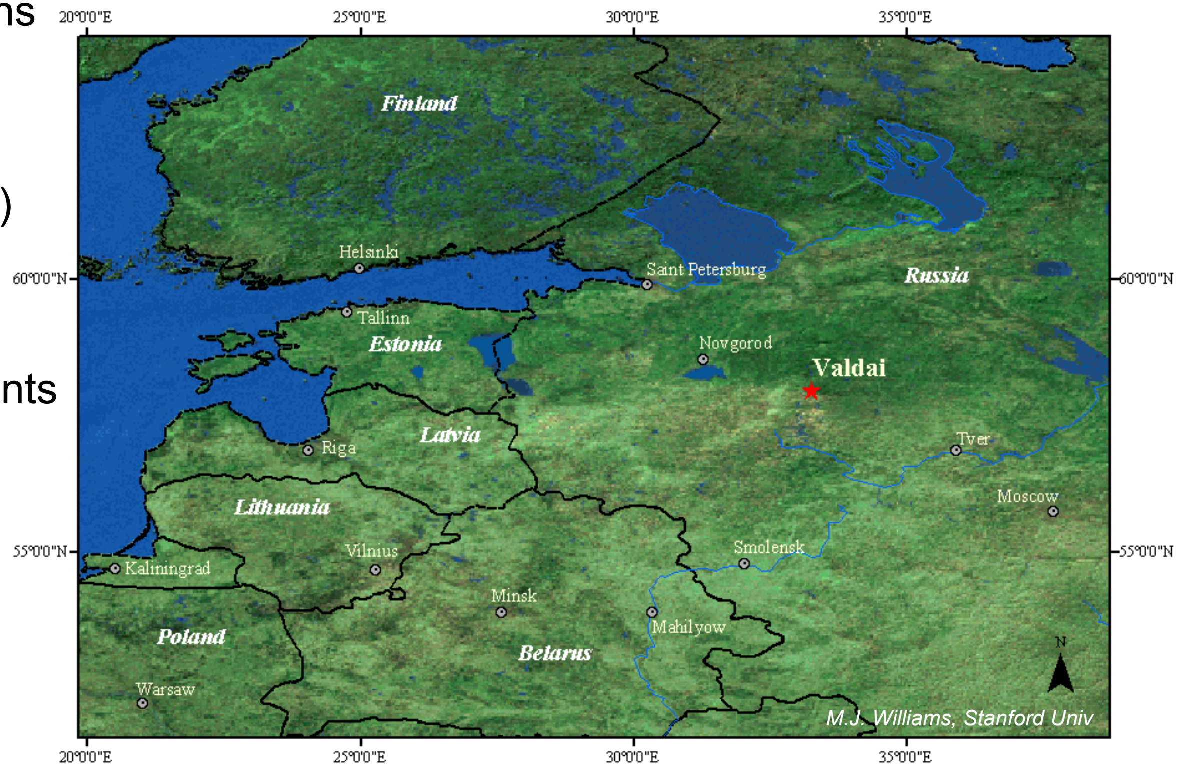
CLM2-Groundwater Model Development, Simulation and Analysis



- ParFlow and TOUGH replace soil column/root zone formulation in CLM
- Infiltration, evaporation and root uptake fluxes passed to ParFlow
- Soil saturation profile passed back to CLM
- Fully-coupled at every timestep

Valdai, Russia research watershed provides an excellent test of coupled model

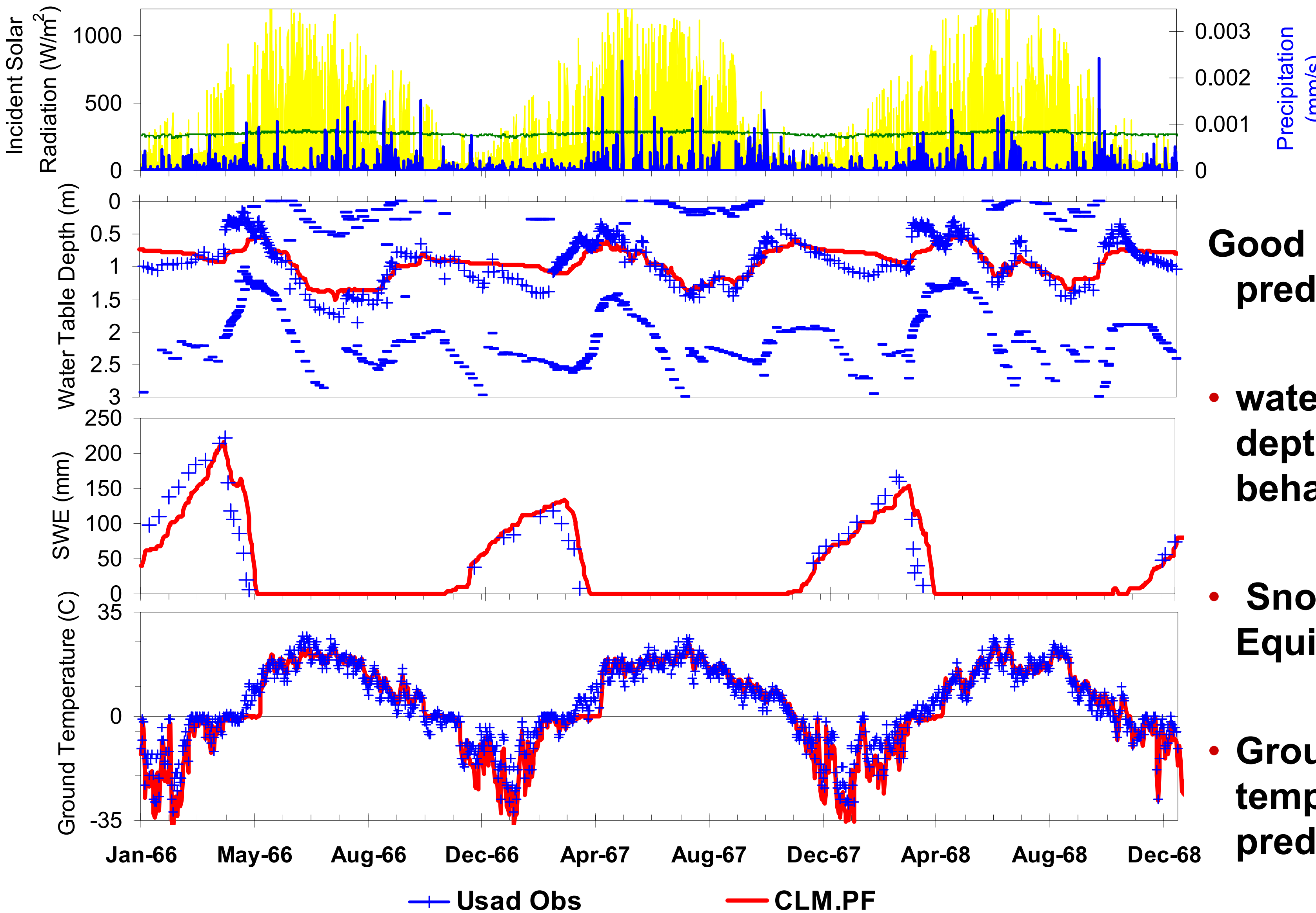
- **Three research watersheds in upper Volga region near St. Petersburg, Russia**
  - Usadievskiy, Tayozhniy and Sinaya Gnilka
  - Small catchment; boreal grassland
  - 18-years continuous observations



- **Good test for models:**
  - Seasonal temperature (+/-50 C)
  - Deep winter snowpack
  - Spring thaw/snowmelt
  - Warm summer precipitation events
- **Good Datasets**
  - Soil moisture, soil temperature
  - Water table
  - Evapotranspiration
  - Runoff
  - Snow water equivalent
- **Used as test bed for LSM model comparison - PILPS 2(d)**

Vinnikov, et al, 1996; Schlosser, et al, 1997; Schlosser, et al, 2000; Luo, et al, 2003

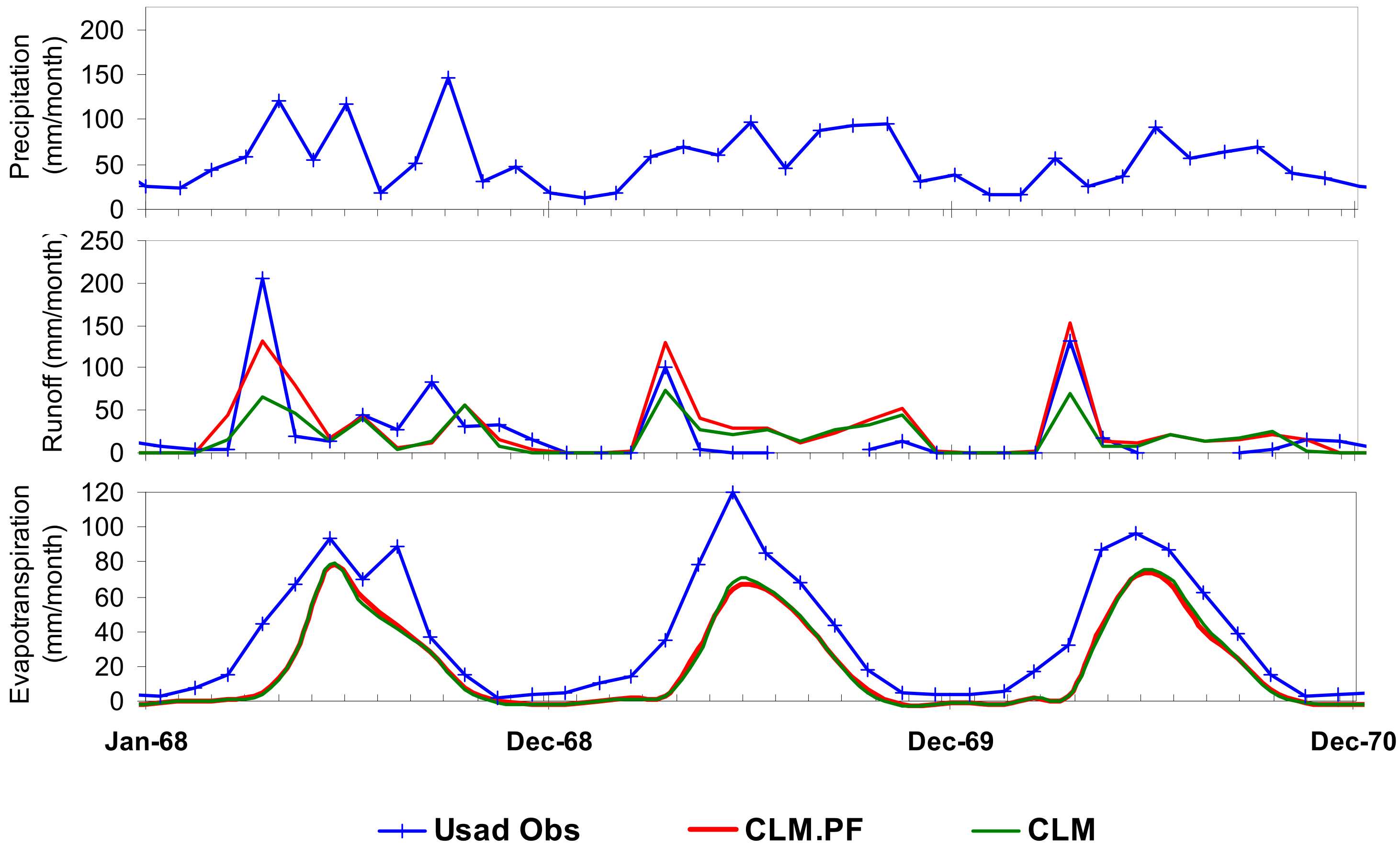
Coupled model agrees with daily-averaged observations



Good predictions:

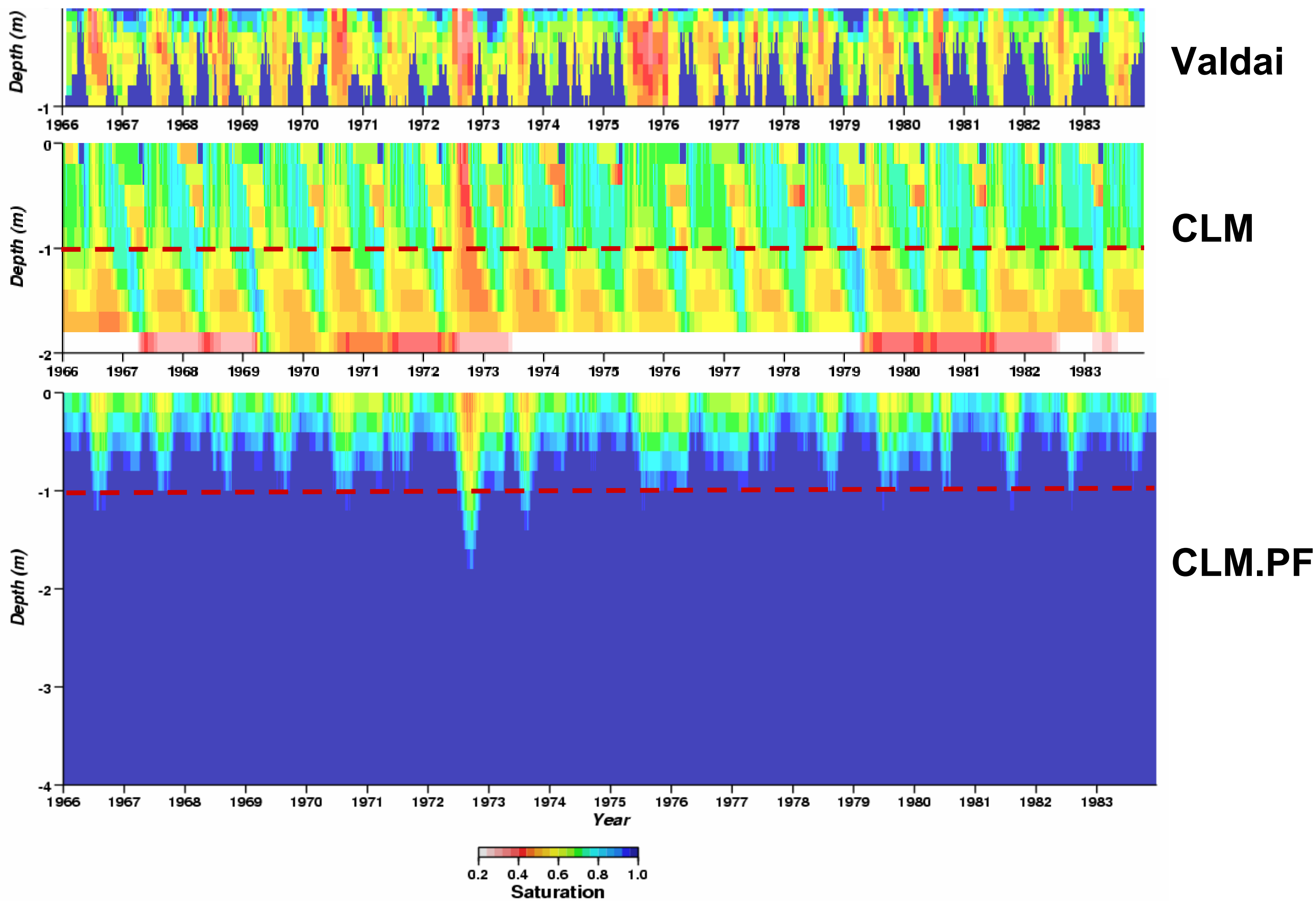
- **water table depth and behavior**
- **Snow Water Equivalent**
- **Ground temperature prediction**

“Shallow Processes” agree well between coupled and uncoupled models, “deeper processes” do not

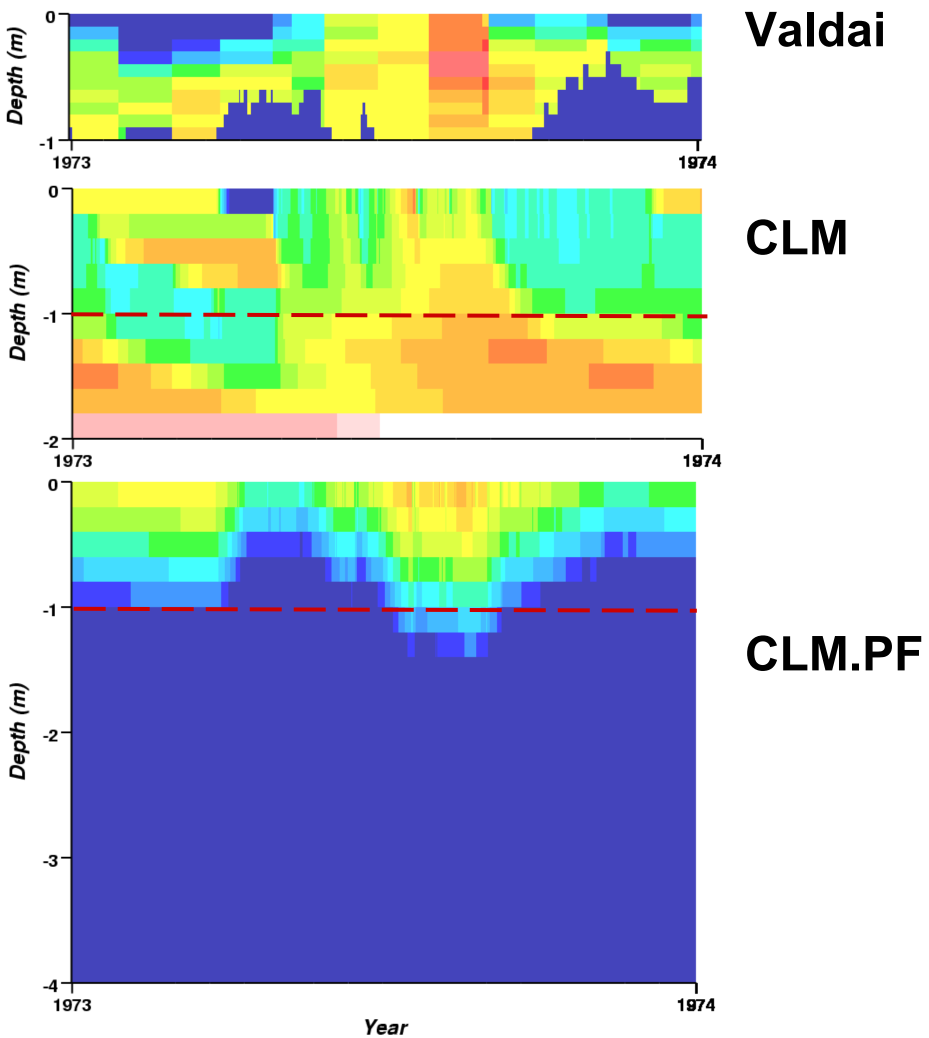


- **Runoff depends on the entire soil column**
- **ET processes depend on the shallow soil layer**

Soil Moisture Predictions are quite different between the coupled and un-coupled models



UC-Berkeley National Lab



One year (1973) soil moisture predictions and observations highlights differences in models.

Summary

- The coupling of MM5 with CLM2 significantly improves the snow depth, snow cover, and surface albedo simulations.

  – MM5-NOAH snow melt is too fast due to unrealistic descriptions of the surface energy balance. This snow melt loss causes stronger evaporation and convective precipitation in the late spring.

  – MM5-CLM2 snow melt generally agrees with observations due to the more advanced snow physics. This results in lower evaporation and little convective precipitation in late spring, as observed.

- Coupling CLM2 with Deep Ground Water

  – Feedback and memory of the water table and “deep” ground processes is important to the surface water and energy budgets, especially for cases with a shallow water table.

  – Distributed model provides even more insight into coupled processes

Ongoing Next Steps

- Advance the distributed groundwater version and apply at Valdai, at an urban watershed, and a transect in the Central Valley (Merced River Basin and the Grassland Area).
- Address parameter scaling issues important to regional scale climate.
- Implement contaminant/pollutant transport.
- Begin a series of long simulations off-line to evaluate the groundwater response.
- Fully couple MM5-CLM2-Deep Groundwater and implement to the transect in the Central Valley.
- MM5-CLM2 is ready for multi-processor, high performance computing control and projected production runs for the US at 50km and CA at 10 km spatial resolution with 6-hr archiving.
- These runs will be coordinated with the CA Climate Intercomparison Studies.

Related Manuscripts 2003-2004

- Brekke, L.D., N.W.T. Quinn, N.L. Miller, and J.A. Dracup, 2004: Climate Change Impacts Uncertainty for San Joaquin River Basin. LBNL 51393, *J. Amer. Water Resources Assoc.*, **40**, 149-164.

- Casadel M. Dietrich WE. Miller NL. 2003: Testing a model for predicting the timing and location of shallow landslide initiation in soil-mantled landscapes. Earth Surface Processes & Landforms. **28**, 925-950.

- Jin, J. and N.L. Miller, 2004: Application of an Advanced Land Surface Scheme in a Regional Climate Model to Improve Snow Simulations. J. Hydrometeorology, (**Submitted**).

- Jin, J, N. L. Miller, S. Sorooshian, and X. Gao, 2003: Relationship between atmospheric circulation and snowpack in the western United States. J. Climate, (**Submitted**).

- Kyriakidis, P.K., N.L. Miller, and J. Kim, 2004: A spatial time series framework for modeling daily precipitation at regional scales. J. Hydrometeorolgy. (**In Press**)

- Maxwell, R.M. and N.L. Miller, 2004: On the development of a coupled land surface and groundwater model for use in watershed management. *J. Hydrometeorology*, (**Submitted**).

- Miller, N.L, K.E. Bashford, and E. Strem, 2003: Potential impacts of climate change on California hydrology. *J. Amer. Water Resources Assoc.*, **39**, 771-784.

- Miller, N.L., A.W. King, M.A. Miller, E.P. Springer, M.L. Wesely and others. 2004: The Doe Water Cycle Pilot Study, LBNL-53826. *Bull. Amer. Meteorological Soc.* (**Accepted**).

- Quinn, N.W.T., L.D. Brekke, N.L. Miller, T. Hienzer, H. Hildalgo, and J.A. Dracup, 2004: Model integration for assessing future hydroclimate impacts on water resources, agricultural production, and environmental quality in the San Joaquin Basin, California. *Envir. Modeling and Software*, **19**, 305-316.